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Evaluation of the Technological Feasibility, and Cost of Selected Control Alternatives Necessary to Meet the Proposed Ohio SO2 Regulations for Industrial Boilers & Processes. Vol. IV. E. I. DuPont de Nemours and Company, Cleveland Sulfuric Acid Plant

GCA Corp, Bedford, Mass. GCA Technology Div.

Prepared for

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16. ABSTRACT

This report presents an evaluation by the GCA Corporation, GCA/Technology Division, of technological feasibility and cost of complying with the proposed Ohio sulfur dioxide regulation (40 FR 52410, November 10, 1975) at the E. I. Dupont de Nemours and Company's Cleveland sulfuric acid plant. The final USEPA Sulfur Dioxide Control Strategy for the State of Ohio Technical Support Documents, Vol. I and II, (EPA 905/2-76-002) may be obtained from NTIS.

After collecting the necessary site and process specific data by means of a plant visit, the evaluation was made emphasizing three commercially available sulfur dioxide abatement systems: Union Carbide's "Pua Sio S" process, the Wellman-Lord system by Davy Powergas, and Dupont's "Tysul" system.

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FINAL REPORT

Contract No. 68-01-3155
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August 1976

Volume IV

E. I. DuPONT de NEMOURS AND COMPANY, CLEVELAND SULFURIC ACID PLANT

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ABSTRACT

The results of an evaluation of the technical feasibility and cost of complying with the proposed SO_2 emission regulation of 6.5 lb SO_2 per ton H_2SO_4 produced are presented in this report. E. I. DuPont de Nemours and Company, Cleveland sulfuric acid plant, was selected as a facility exemplifying the impact of the proposed regulation. The "PuraSiv S" process, the Wellman-Lord process and DuPont's "Tysul" process were emphasized in this study.

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SECTION I

SUMMARY AND CONCLUSIONS

E. I. DuPont de Nemours and Company, Inc. manufacture sulfuric acid by the conventional contact process at their Cleveland Plant in Cuyahoga County. The technical feasibility and cost of meeting the proposed Ohio regulation limiting sulfur dioxide emission from sulfuric acid production units to 6.5 lb SO_2/ton sulfuric acid (100 percent) produced were investigated with regard to the DuPont Plant.

Four commercially available SO_2 abatement systems were evaluated:

- Adsorption on molecular sieves (Union Carbide Corporation's "PuraSiv S" process)
- Absorption by a sodium sulfite-bisulfite system (the Wellman-Lord system by Davy Powergas, Inc.)
- Absorption by a hydrogen peroxide system (DuPont's "Tysul" system)
- Dual absorption.

These systems are technically capable of meeting the proposed regulation but a retrofit dual absorption system may not be applicable in all situations.

Capital, operating, and annualized costs were derived for the PuraSiv S system based on capital expense and utility usage plots furnished by Union Carbide. The total capital investment and annual charges for the "Tysul" process were furnished by DuPont. Costs of the Wellman-Lord system were estimated from recent cost data in the technical literature.

The estimated capital requirements for the three systems were $2.74 million, $2.8 million, and $3 million, respectively. The attendant total annualized charges including cost of capital, depreciation, net operating cost, etc. were $714,000, $750,000, and $750,000. All costs represent May 1976 prices. However, the annual cost of the "Tysul" process may be higher for companies that must purchase hydrogen peroxide in the open market.

SECTION II

PROCESS AND SITE DESCRIPTION

E. I. DuPont de Nemours and Company, Inc., Cleveland Industrial Chemical Department Plant, was visited on May 18, 1976. This facility is located on a 38 acre site fronting the Cuyahoga River at 3981 Independence Road, Cleveland, Ohio 44115. About 300 people are employed at this plant which produces basic inorganic chemicals. Products include sulfuric acid, sodium bisulfate, hydrochloric acid, zinc chloride, zinc ammonium chloride, and soluble silicates. The purpose of the plant visit was to collect site and process specific data necessary to determine the technical feasibility and cost of complying with the proposed regulation for control of SO_2 emissions from sulfuric acid manufacturing units. Mr. E. A. Spearing, Environmental Coordinator at the Cleveland Plant, represented DuPont. The sulfuric acid production facilities were surveyed, site and process information was provided, and manufacturing operations and SO_2 control devices were discussed.

Sulfuric acid is produced by the Leonard Monsanto contact process using elemental sulfur as a raw material. A process flow diagram is shown in Figure 1.[1] Molten sulfur is burned with dry air in a sulfur furnace to produce SO_2. Heat is recovered in a waste heat boiler from the cooling of the hot SO_2 gas. The SO_2 is then sent to a Monsanto four-pass converter where SO_2 is oxidized to SO_3 in the presence of a vanadium catalyst. Interstage cooling is required to secure high yields of SO_3. Waste heat from this operation is also utilized in production of steam. The SO_3 gas stream is sent to absorption towers where the SO_3 is absorbed in strong acid. After passing through mesh pad mist eliminators on the absorbers, the tail-gas is sent to a stack.

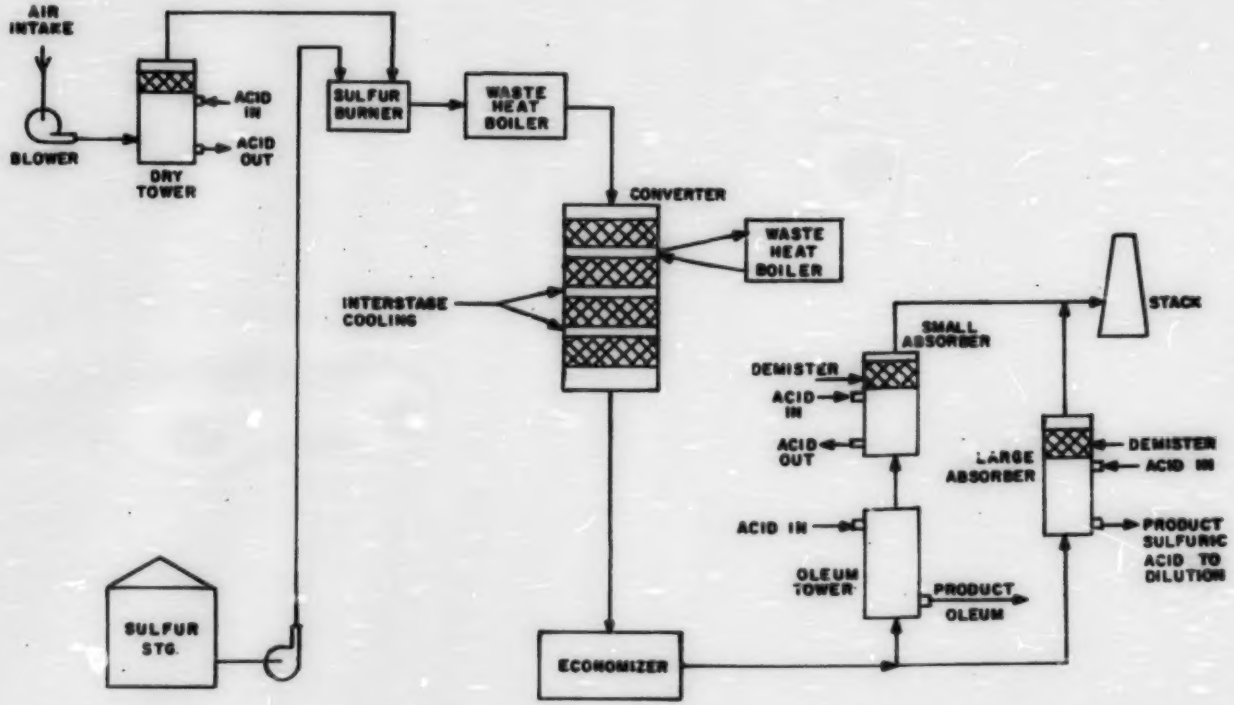

Figure 1. DuPont-Cleveland sulfuric acid manufacturing process flow diagram

The process is manually controlled. Instrumentation includes recorders on sulfur feed, inlet gas strength, recirculating acid strength, and exit sulfur dioxide concentration. The gas temperature profile throughout the system is also monitored.[1]

Waste heat from the sulfuric acid production process is used to generate 360 psi steam for system use. After let down to 110 psi, the steam is delivered to other operations on the site. Sulfuric acid products are 60°Be (77.67 percent), 66°Be (93.19 percent), 99 percent acid, and 20 percent oleum (104.5 percent acid equivalent).[1] The plant is currently operating under the SO_2 emission limitation prescribed in the 1969 Cleveland Air Pollution Regulations which prohibits SO_2 concentrations greater than 2000 ppm in the stack. The proposed Ohio SO_2 regulation[2] §52.1881(b)(11) quoted below is more stringent:

> "(11) No owner or operator of a sulfuric acid production unit shall cause or permit the emissions of sulfur dioxide from the unit in excess of 6.5 lbs. SO_2/ton of H_2SO_4 produced (expressed as 100% H_2SO_4). The provisions of this subparagraph shall not be applicable to processes operated in conjunction with the desulfurization of by-product coke oven gas, provided that the emission limitation set forth in paragraph (b)(12) of this paragraph has been complied with."

Currently, the acid plant is emitting a stack gas with the characteristics described in Table 1.

Table 1. ACID PLANT TAIL GAS COMPOSITION AND FLOW

	Normal	Maximum
Flow rate, scfm	27,000	30,000
Temperature, °C	90	90
Pressure	Ambient	Ambient
SO_2 concentration, ppm	1,600	2,000
SO_3 concentration, mg/scf	0.5	[a]
Acid mist concentration, mg/scf	2	4

[a] SO_3 concentration in stack may be appreciable under abnormal absorber operation.

An SO_2 control system is necessary if the plant is to comply with the proposed regulations. The system must be designed to reduce emissions to less than the prescribed 6.5 lb SO_2/ton acid at all normal production levels. Based on design criteria furnished by DuPont, the maximum allowable stack concentration would be 390-550 ppm SO_2 with the variation due to changes in converter inlet strength. The unit must be designed to handle the flow rates specified previously. The abatement system must be highly reliable, operating 24 hours per day to match acid plant performance. The following utilities are available at the site:

- electricity, 480 volts
- water, Cleveland City water
- steam, 360 psig, 110 psig
- fuel, No. 2 fuel oil, 0.3 percent sulfur.

SECTION III

EMISSION CONTROL TECHNOLOGY FOR SULFURIC ACID PLANT TAIL GAS

At this time, the most advanced processes for the removal of sulfur dioxide from sulfuric acid plant tail gas are the following:

- Adsorption on molecular sieves (PuraSiv S)
- Absorption by sodium sulfite-bisulfite system (Wellman-Lord)
- Absorption by hydrogen peroxide system (DuPont "Tysul")
- Dual absorption.

These processes are all being used commercially in the United States and are technically capable of achieving the proposed SO_2 emission limitation of 6.5 lb SO_2/ton acid produced. The dual absorption system, however, cannot reduce SO_2 concentrations below 500 ppm because SO_2 - SO_3 equilibrium is limiting. In some retrofit situations, SO_2 concentrations will need to be reduced below 500 ppm to achieve the 6.5 lb SO_2/ton acid emission limit.

The PuraSiv S process and the "Tysul" process have been developed since the new source performance standard of 4 lb SO_2 per ton H_2SO_4 was implemented, while the Wellman-Lord process and the dual adsorption process comprised the control technology basis for the new source performance standard.[3] State emission standards vary from 4 lb SO_2/ton H_2SO_4 to about 40 lb SO_2/ton H_2SO_4. Arizona, Colorado and New York have the strictest standard at 4 lb SO_2/ton H_2SO_4 for existing sources.

PuraSiv S PROCESS[4,5]

The PuraSiv S process, developed and marketed by Union Carbide Corporation,* is a fixed-bed adsorption system for removing SO_2, SO_3, and acid mist from sulfuric acid plant tail gas. The adsorbent is a tailor-made molecular sieve, also produced by Union Carbide. Upon regeneration of the molecular sieve, the concentrated SO_2 stream is recycled to the acid plant. Recovered SO_2 contributes a 2 to 3 percent increase in acid production.

Regeneration of the loaded molecular sieve beds is accomplished by purging with hot, dry air. There are two versions of the process which differ in the method of drying the air stream. If a source of acid-dried air is available as in DuPont's Cleveland Plant, this air is used for bed regeneration and the process flow diagram will be similar to that in Figure 2. If acid-dried air is not available, the regeneration air is supplied by drying ambient air with an additional molecular sieve as shown in Figure 3.[5]

In both versions, the tail gas passes through a blower, a cooler, and a high efficiency mist eliminator. The mist eliminator decreases acid mist in the tail-gas stream to less than 0.1 mg/scf. The tail gas then passes through a molecular sieve bed for selective adsorption of SO_2 and SO_3. The molecular sieve is more effective and longer lasting when the tail gas is completely dry because water competes with SO_2 in the sieve lattice. Drying is accomplished by using a dessicant grade molecular sieve located in the adsorber vessels in a compound

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*Union Carbide Corporation
Tarrytown, New York

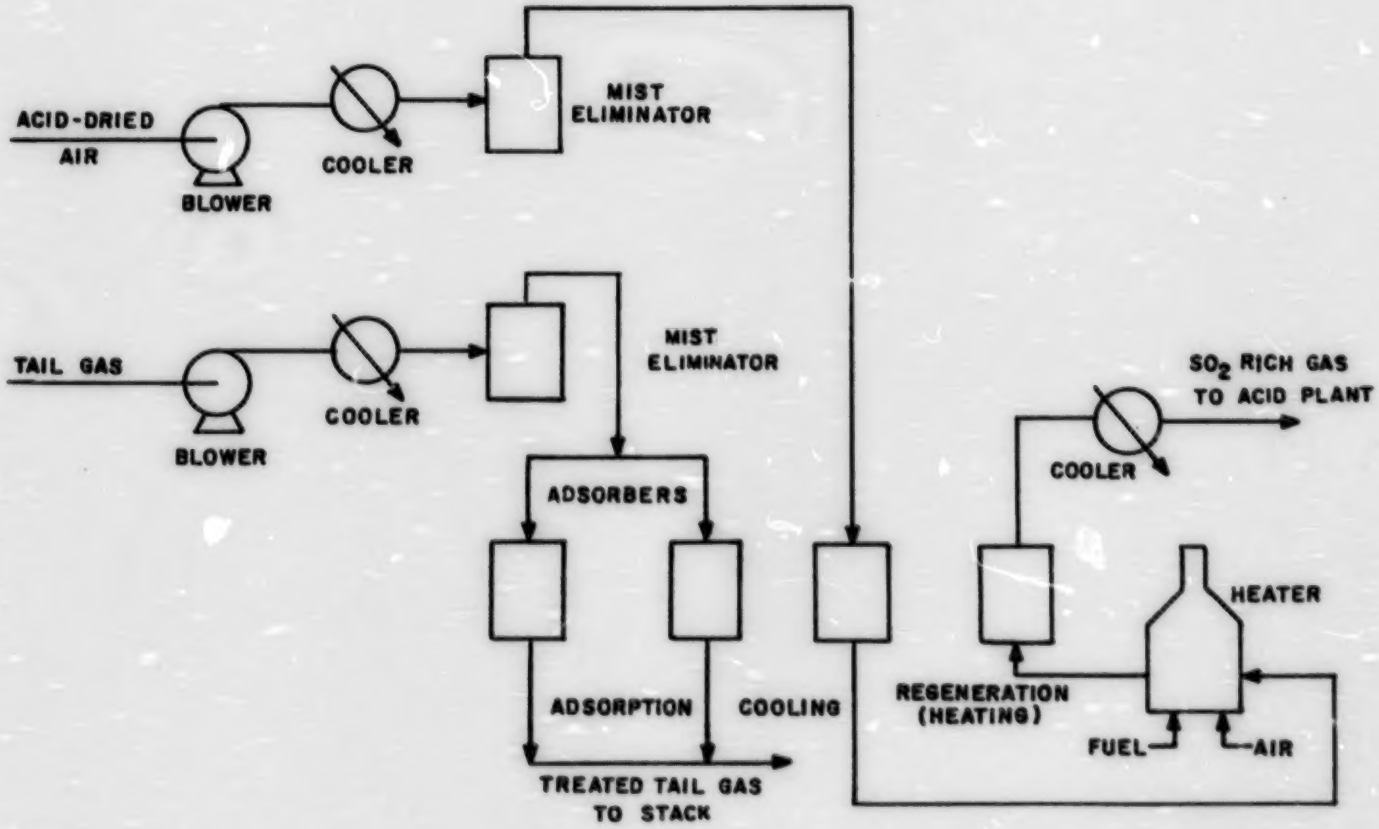

Figure 2. Flow sheet of PuraSiv S process with acid-dried air regeneration[5]

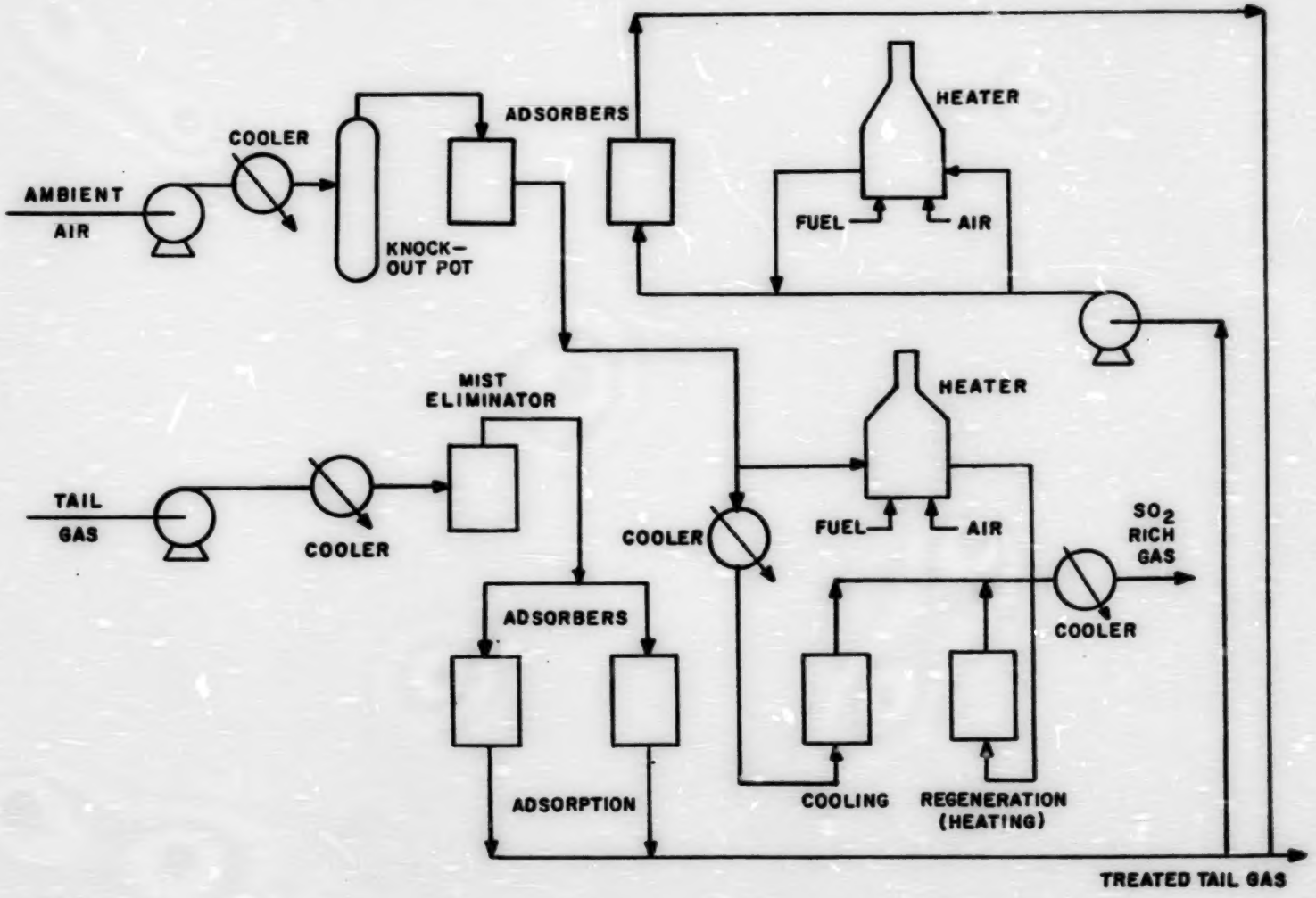

Figure 3. Flow sheet of PuraSiv S process with sieve-dried air regeneration[5]

bed arrangement. After passing through the adsorbers, the tail gas is discharged to the atmosphere.[5]

In the acid-dried version (Figure 2), regeneration air from the acid plant drying tower containing 50 to 100 ppm water passes through a blower, a cooler, and a high efficiency mist eliminator. The cool regeneration air is first used to cool the adsorber and molecular sieves which are hot from the previous regeneration step. This heats the air and reduces the moisture content by adsorption to less than 1 ppm. The air is then passed through a reheat furnace and used to regenerate the loaded molecular sieve. The hot air strips the SO_2, SO_3, and H_2O from the adsorbent bed. The SO_2-rich stream is cooled and recycled to the acid plant. The four adsorber vessels shown in Figure 2 are provided with the necessary switching valves for continuous cyclic operation. At any particular time, two adsorbers are in the adsorption phase, one is in the air cooling phase, and one is in the air heating (regeneration) phase.[4]

The first commercial unit was installed on a Coulton Chemical Corporation sludge acid plant in Oregon, Ohio. The unit went on stream in February 1973. Immediately afterward, Union Carbide performed a six-month study on the system. The availability of the unit was very good, down only three times for a total of 56 hours. SO_2 recovery from the tail gas was greater than 99 percent. Average daily effluent SO_2 concentration was in the 15 to 25 ppm range, equivalent to a daily emission rate of less than 0.4 lb SO_2/ton acid produced. The maximum instantaneous effluent level was 236 ppm during upset conditions. The daily mean SO_2 concentration in the off gas was always less than 50 ppm, equivalent to 0.7 lb SO_2/ton acid.[4]

In November 1973, the original molecular sieve adsorbent installed in February 1973 was replaced with a second generation sieve designed for

longer life. During tests on this sieve in February 1975 emissions were less than 1 lb SO_2/ton H_2SO_4. Operation of the unit is fully automatic and there are no by-products or waste streams. In addition, acid production is increased 2 to 3 percent by recycling the recovered SO_2. It is also possible to increase production since the SO_2 strength to the converter may be increased.[4]

Estimated costs of installing and operating a PuraSiv S system at the DuPont Cleveland Plant are presented in Section IV.

"TYSUL" PROCESS[1,6]

The "Tysul" SO_2 abatement process developed by DuPont* uses a tail gas scrubber to react sulfur dioxide in the entering stream with "Tysul" to produce sulfuric acid. "Tysul" is DuPont's trademark for a specially stabilized 70 percent hydrogen peroxide solution. A flow diagram of the process is shown in Figure 4. The acid plant tail gas is scrubbed with 35 to 50 percent sulfuric acid containing 0.1 to 0.5 percent "Tysul." The SO_2 is absorbed in the sulfuric acid and reacts with the peroxide in the liquid phase to form sulfuric acid according to the following equation:

$$SO_2\ (g) + H_2O_2\ (\ell) \xrightarrow{H_2SO_4(aq)} H_2SO_4(aq)$$

The yield varies with operation conditions, but 95 percent conversion of the peroxide is typical.[1]

The addition of peroxide is automatically controlled to maintain a given SO_2 concentration in the exit stack. The SO_2 effluent is continuously monitored by a DuPont 400 series analyzer. As the off gas is passed

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*DuPont Company, Environmental Improvement Section, Chestnut Run Laboratory, Wilmington, Delaware 19898.

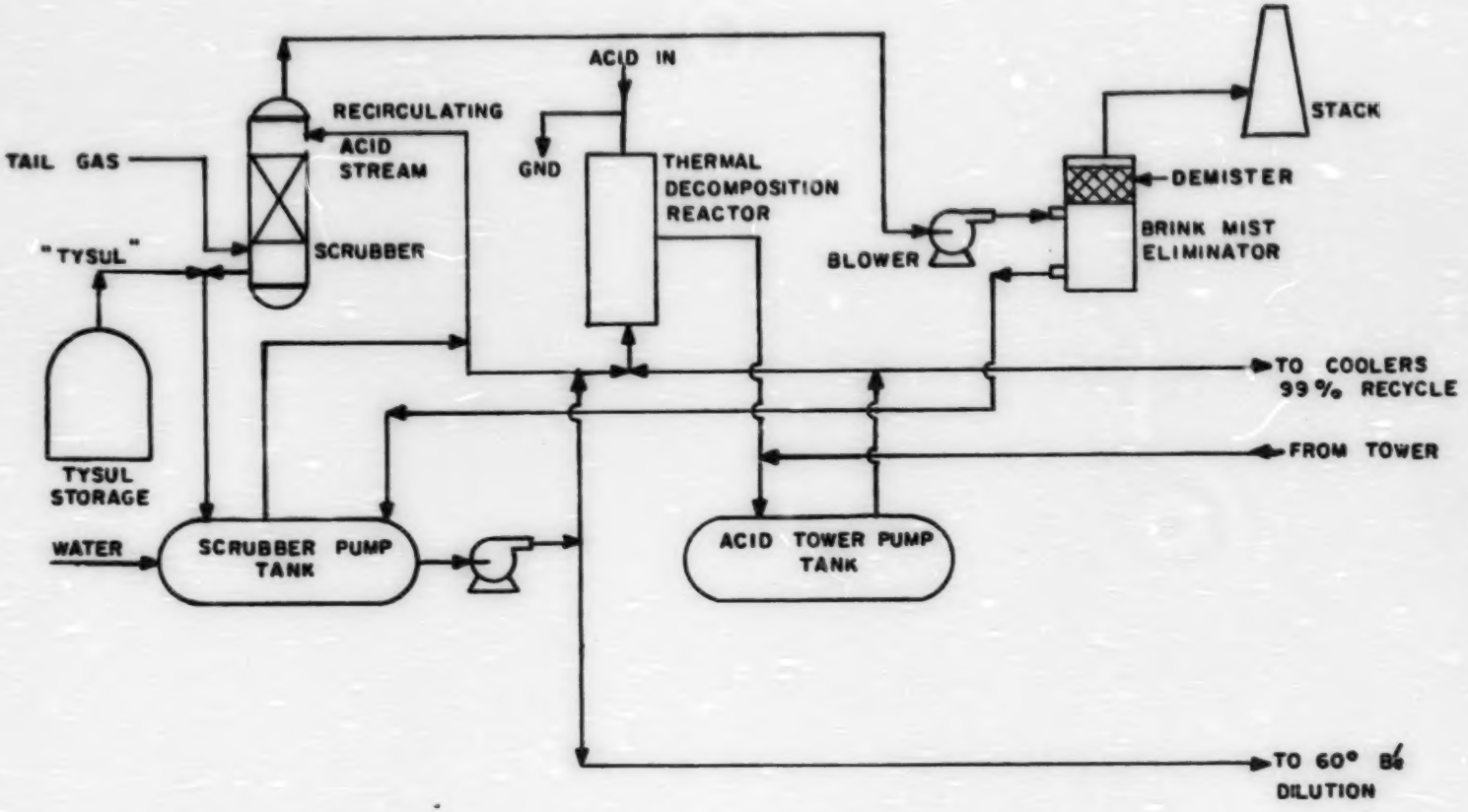

Figure 4. DuPont "Tysul" SO_2 abatement process[1]

through the scrubber, it is humidified and cooled. Evaporative losses are made up by the addition of city water, also automatically controlled. The humidified, SO_2-abated gas stream passes through a York entrainment separator as it leaves the scrubber and then through a high efficiency mist eliminator before discharging to an elevated stack.[1]

The scrubbing liquor is continuously recirculated. A purge stream is drawn off to maintain a constant sulfuric acid concentration via an automatic flow control loop. The purge stream is passed through a thermal decomposition reactor prior to return to the sulfuric acid plant. Residual peroxide is thereby decomposed according to the following equation:

$$2\ H_2O_2\ (aq) \xrightarrow[\text{strong acid}]{> 120^oC} 2\ H_2O + O_2\ (g)$$

The purge stream is then returned to the acid plant as a substitute for normal dilution water in the absorber. The peroxide is decomposed to avoid discoloration of the product acid. In the event of a thermal decomposition reactor breakdown, the purge stream is either temporarily held up in the scrubber pump tank or transferred untreated to the 60°Bé acid dilution pump tank.[1]

The battery limits plant also includes facilities for "Tysul" unloading and storage. The "Tysul" is transferred continuously from storage to the scrubber pump tank.

The "Tysul" process has been operating successfully at DuPont's East Chicago Plant since November 1972, and is meeting the East Chicago Air Control Ordinance level of 6.5 pounds of sulfur dioxide per ton of sulfuric acid produced. The process is stable and acid plant upsets are automatically moderated by the scrubbing facility. There are no waste streams and no additional operating labor requirements.

The DuPont Cleveland Plant has selected this control alternative for meeting the proposed 6.5 lb SO_2/ton H_2SO_4 emission limitation. Costs for the process as estimated by DuPont are provided in Section IV. It must be noted, however, that DuPont is not actively marketing this abatement process at this time,[6] probably due to the high cost of H_2O_2 ($0.4/lb) on the open market. The cost might be prohibitive in situations with high inlet SO_2 concentrations.

WELLMAN-LORD PROCESS[7,8,9]

The Wellman-Lord process is a regenerative SO_2 recovery process available from Davy-Powergas, Inc. A process flow diagram is shown in Figure 5. Tail gas from the acid plant is scrubbed with a lean sodium sulfite (Na_2SO_3) solution which absorbs SO_2, converting the sodium sulfite to sodium bisulfite as follows:

$$SO_2(g) + Na_2SO_3\ (aq) + H_2O(\ell) \rightarrow 2\ NaHSO_3$$

The clean gas leaves the absorber through a mist eliminator.

The rich bisulfite solution is fed to an evaporator/crystallizer regeneration system after preheating. Heat supplied in the evaporator causes the decomposition of the bisulfite in the reverse of the above reaction:

$$2\ NaHSO_3 \xrightarrow{\Delta} Na_2SO_3\ (s) + SO_2(g) + H_2O(g)$$

The SO_2 and water vapor pass overhead from the evaporator to a primary condenser, where 80 to 90 percent of the water is removed. The condensate is stripped with steam to remove dissolved SO_2. Overhead vapors from the stripper are mixed with vapor from the primary condenser and sent to a secondary condenser. Condensate is returned to the top of the stripper, and the vapor stream containing approximately

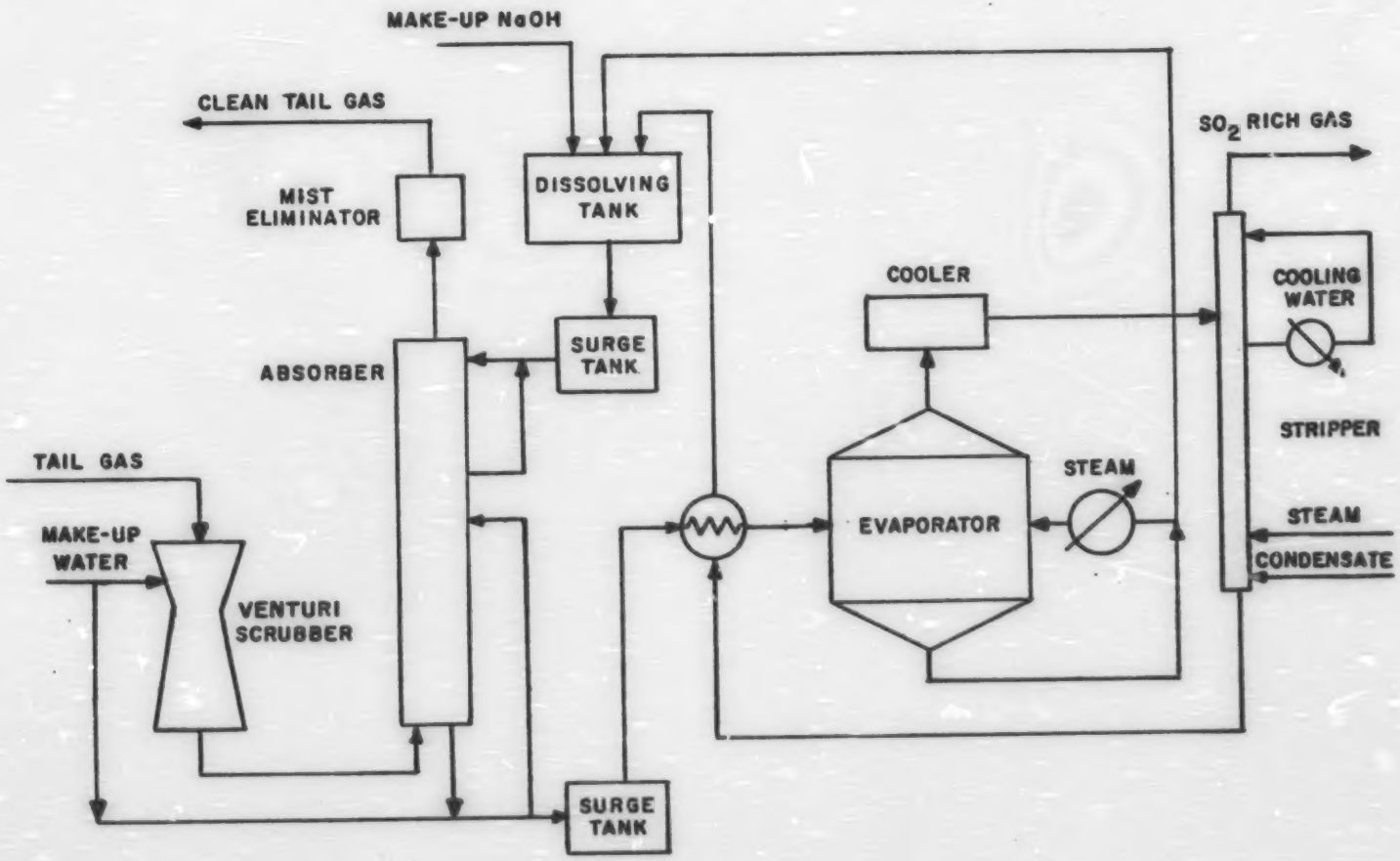

Figure 5. Flow sheet of Wellman-Lord process[4]

85 percent SO_2 and 15 percent water is recycled to the sulfuric acid plant air dryer.

The oxidation of a small amount of sodium sulfite to sodium sulfate creates the need to purge a portion of the solution from the system. This creates a chemical makeup requirement and potential waste disposal problem. Chemical requirements have been minimized by a system which selectively removes the sulfate by crystallization. The concentrated purge stream from this system can be dried for sale or disposal of the sulfate. Davy-Powergas is currently engaged in the development of processes to chemically reduce the sulfate back to sodium sulfite.

There are now 17 Wellman-Lord installations in commercial service worldwide, desulfurizing tail gas from sulfuric acid plants, Claus plants, and flue gas from boilers. Three of these are treating tail gas from acid plants in the United States as listed in Table 2. An additional 13 Wellman-Lord plants have been licensed (worldwide) and are in design or under construction.

Table 2. WELLMAN-LORD SO_2 RECOVERY FACILITIES TREATING SULFURIC ACID PLANT TAIL GAS[9]

Plant	Size of plant, tons H_2SO_4/day	Tail gas flow, scfm	Start-up date
Olin Chemical Co. Curtis Bay, Maryland	1,000	78,046	June, 1973
Allied Chemical Corp. Calumet, Illinois	500	29,850	Nov., 1972
Olin Chemical Co. Paulsboro, N.J.	700	45,000	July, 1970

Full-scale units on U.S. sulfuric acid plants have demonstrated on-stream availability of greater than 97 percent over 12 1/2 plant-years of operation. Effluent SO_2 levels of 200 ppm in the stack gas have been

consistently achieved. This is approximately 3.1 lb SO_2/ton acid, well below the emission limitation in the proposed Ohio SO_2 regulations.

DUAL ABSORPTION PROCESS[10]

Dual absorption is an alternate design of the sulfuric acid plant which achieves higher sulfur to sulfuric acid conversion and thus, reduced emissions. Tail gas from the primary absorber is reheated and returned to a converter, usually one stage, where more SO_2 is catalytically oxidized to SO_3 per the basic contact reaction:

$$SO_2 + 1/2\ O_2 \rightleftarrows SO_3$$

The thermodynamics of the reaction are well documented.* The additional conversion of SO_2 to SO_3 is possible because the primary absorber tail gas has a higher O_2:SO_2 ratio (normally > 4:1) than the gas sent to the primary converter (a ratio of 1.5:1). However, the SO_3 yield is still limited by chemical equilibrium and kinetics. Dual absorption can only be used to reduce the SO_2 concentration in the off gas to around 500 ppm.[10] In plants using low converter inlet gas strength (SO_2 concentration of 7 percent) the dual absorption system will not be able to achieve the 6.5 lb SO_2/ton acid limit because exit SO_2 concentrations below 400 ppm are required. The process would be applicable for plants operating at inlet gas concentrations of approximately 9 percent SO_2 or greater.

A process flow diagram for a retrofit dual absorption system is presented in Figure 6.

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*Duecker, W. W. and J. R. West. The Manufacture of Sulfuric Acid. Reinhold. 1959. pp. 135-185.

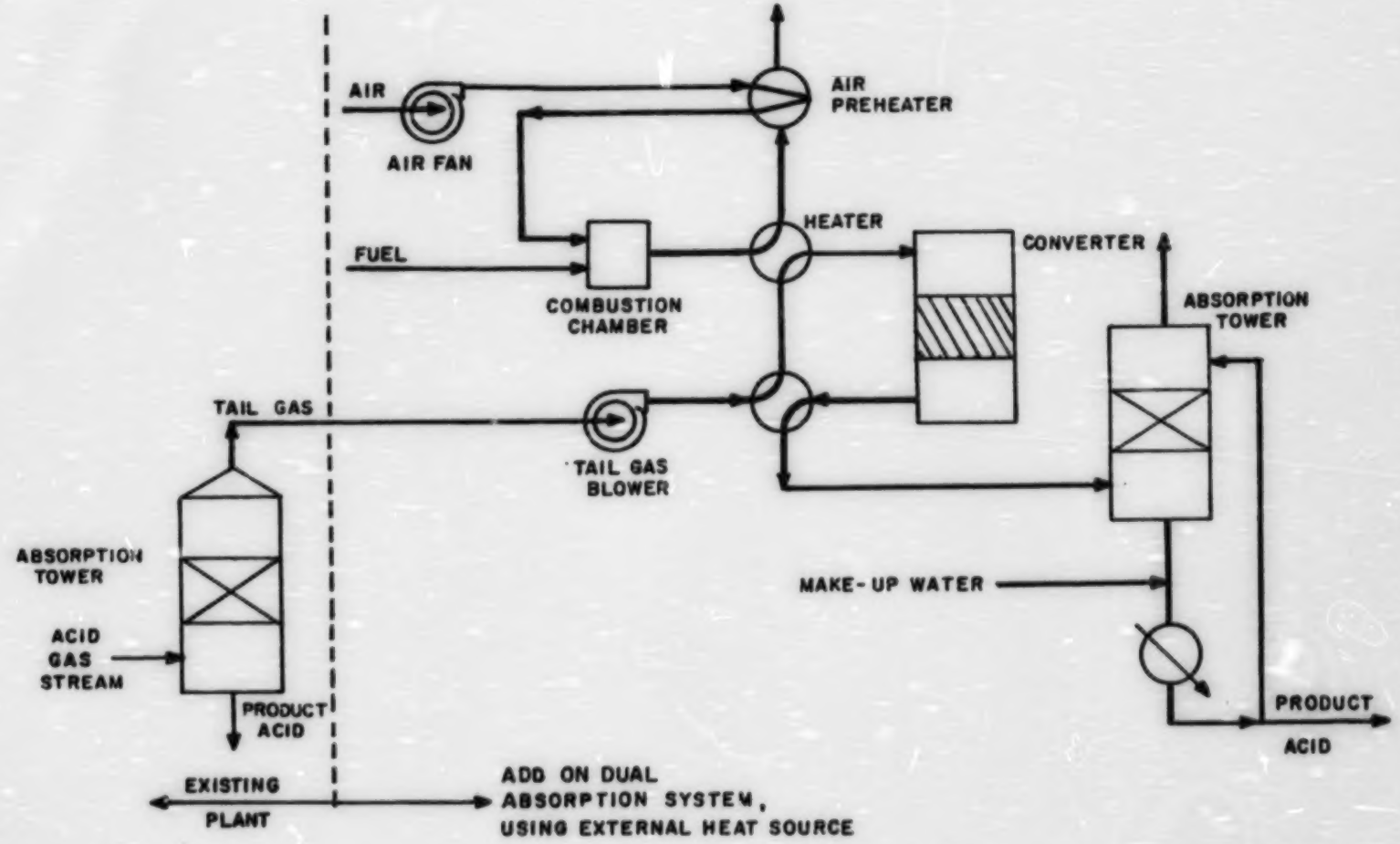

Figure 6. Flow sheet of retrofit dual absorption process using external heat source[10]

The gas from the secondary converter is sent to a secondary absorber where the SO_3 is absorbed to form more acid. Retrofit systems can differ significantly, the key feature being the source of heat for reheating the tail gas. The scheme shown in Figure 6, obtaining heat by burning additional fuel, is the most applicable.

SECTION IV

COST OF CONTROL SYSTEMS

A detailed cost comparison of the PuraSiv S, Wellman-Lord, and dual absorption emission control processes has recently been made by Battelle-Columbus Laboratories.[5] DuPont provided the total capital investment and annualized operating expense for controlling emissions from the Cleveland sulfuric acid plant with their "Tysul" abatement system. Total annualized cost of all systems were very similar.

GCA has prepared a detailed, up-to-date cost estimate for SO_2 emission control utilizing the PuraSiv S process at the DuPont Cleveland Plant. This cost estimate is for a system designed according to specifications provided in Section II. Battery limits plant cost and utility, material, and labor requirements were based primarily on plots provided by Union Carbide Corporation and published by Battelle.[5] The operating requirements, the associated unit costs, and resulting daily operating costs are presented in Table 3. Capital and annualized costs and the components used to evaluate these costs are given in Table 4. The annualized costs were derived according to an accounting method based on the Utility Financing Method as modified by the Panhandle Eastern Pipeline Company.[12]

The estimated total capital requirement for the PuraSiv S system is $2,736,000 with an attendant average annualized cost of $714,000 which includes an annualized capital cost, federal taxes, and operating costs. DuPont has estimated the capital investment of a "Tysul" SO_2 abatement facility for their Cleveland acid plant to be $2.8 million with an annualized operating expense of $750,000.[1] Based on the cost comparisons

Table 3. UTILITY, MATERIAL, AND LABOR REQUIREMENTS AND COSTS FOR A "PuraSiv S" SYSTEM AT DUPONT'S CLEVELAND PLANT

	Daily usage	Unit cost	Average daily cost, $
Utilities			
Power	15,000 kWh	$0.02/kWh[a]	300.0
Cooling water	807,000 gal	$0.06/1000 gal[b]	48.4
No. 2 fuel oil	30 x 10^6 Btu	$2.14/$10^6$ Btu[c]	64.3
Total			412.7
Materials			
Adsorbent	-	$150,000/yr[d]	411.0
Maintenance	-	1.5% fixed capital investment/yr	108.5
Total			519.5
Labor			
Operator	1 hr	$8/hr	8.0
Maintenance	-	1.5% fixed capital investment/yr	108.5
Total			116.5
Total			1,048.7

[a] Ohio Edison.

[b] Once-through cooling water.

[c] $0.30/gal, 140,000 Btu/gal.

[d] Adsorbent contract cost, acid-dried regeneration, two-year guarantee, 100 ppm SO_2 in off gas.[5]

Table 4. COSTS FOR "PuraSiv S" SYSTEM FOR DUPONT'S CLEVELAND PLANT, 10^3, MAY 1976

	10^3
Capital requirement	
Battery limits plant installed (BLP)[a]	2,200.0
Site preparation and utilities,[b] 20 % of BLP	440.0
Fixed capital investment (FCI)	2,640.0
Working capital,[c] 20% of gross operating cost	95.9
Total capital requirement	2,735.9
Annual operating cost	
Labor[d]	42.5
Administrative and general overhead,[c] 60% of labor	25.5
Utilities[d]	150.6
Materials[d]	189.6
Local taxes and insurance,[c] 2.7% of FCI	71.3
Gross operating cost	479.5
Sulfur dioxide credit, $50/ton[e]	-93.1
Net annual operating cost	386.4
Annualized cost	
Annualized capital cost[f]	278.7
Federal income tax[c,g]	49.0
Net operating cost	386.4
Average annual cost	714.1

[a]Estimated from Union Carbide cost plots.[5]

[b]Site preparation and cost to bring utilities to battery limits.

[c]Based on Utility Financing Method as modified by the Panhandle Eastern Pipeline Company.[12]

[d]See Table 3.

[e]Conservative estimate based on inlet gas concentration of 2000 ppm SO_2 and sulfuric acid price of $50/ton[11] ($77/ton of SO_2 in acid). Pure SO_2 sells for about $150/ton.

[f]Capital costs are amortized at a discounted cash flow rate of 8% over 20 years. This method yields an average annual capital cost (including depreciation) of 10.18 percent of total capital investment.

[g]Average federal income tax = 1.731 percent of sum of total capital investment and working capital.

made in the Battelle study,[5] the capital requirement of a Wellman-Lord abatement system would be near $3 million, and the total annualized cost would be $750,000. These costs are summarized in Table 5.

The estimated cost of all control systems is very close; and relative cost may vary for other plant sizes and operating conditions. DuPont has selected the DuPont "Tysul" SO_2 abatement process for their Cleveland Plant.

Table 5. ESTIMATED INVESTMENT AND ANNUALIZED COSTS FOR RETROFITTING DUPONT'S CLEVELAND SULFURIC ACID PLANT WITH SO_2 ABATEMENT SYSTEMS

	Union Carbide "PuraSiv S"	DuPont "Tysul"	Davy-Powergas Wellman-Lord
Total capital investment, million $	2.74	2.8	3.0
Total annualized cost,[a] thousand $	714	750	750

[a]Includes annualized capital charge, annual operating and maintenance charges, taxes, etc., see Table 4.

SECTION V

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